Spectra of accretion disks in active galactic nuclei & X-ray binaries

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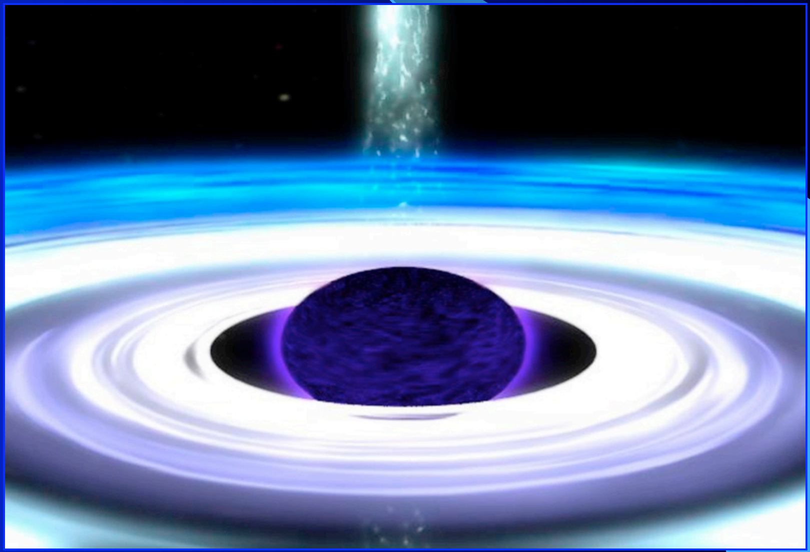
Outline

- Introduction to X-ray spectra of disks
- MCG-6-30-15 : physics of a spinning BH
- Are disk signatures generic amongst AGN?
- X-ray binary sources (in brief).
- The future and Constellation-X

I : X-ray signatures of disks in black hole systems

- Accretion flow produces hard X-ray continuum (thermal Comptonization)

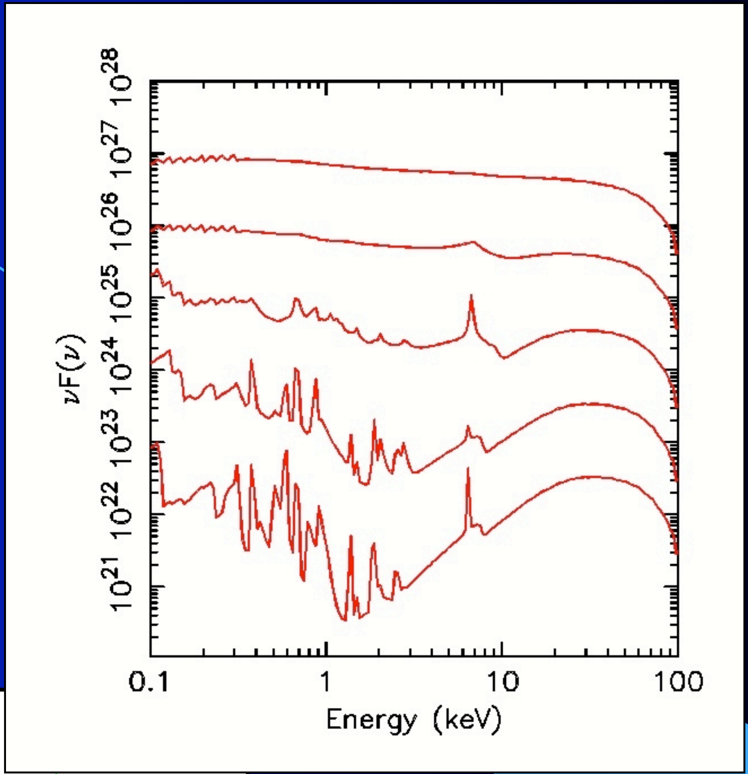
- Irradiated optically-thick matter will
  - Compton backscatter X-rays (Lightman & White 1988; Guilbert & Rees 1988)
  - Cause fluorescence (strongest line is iron Kα)

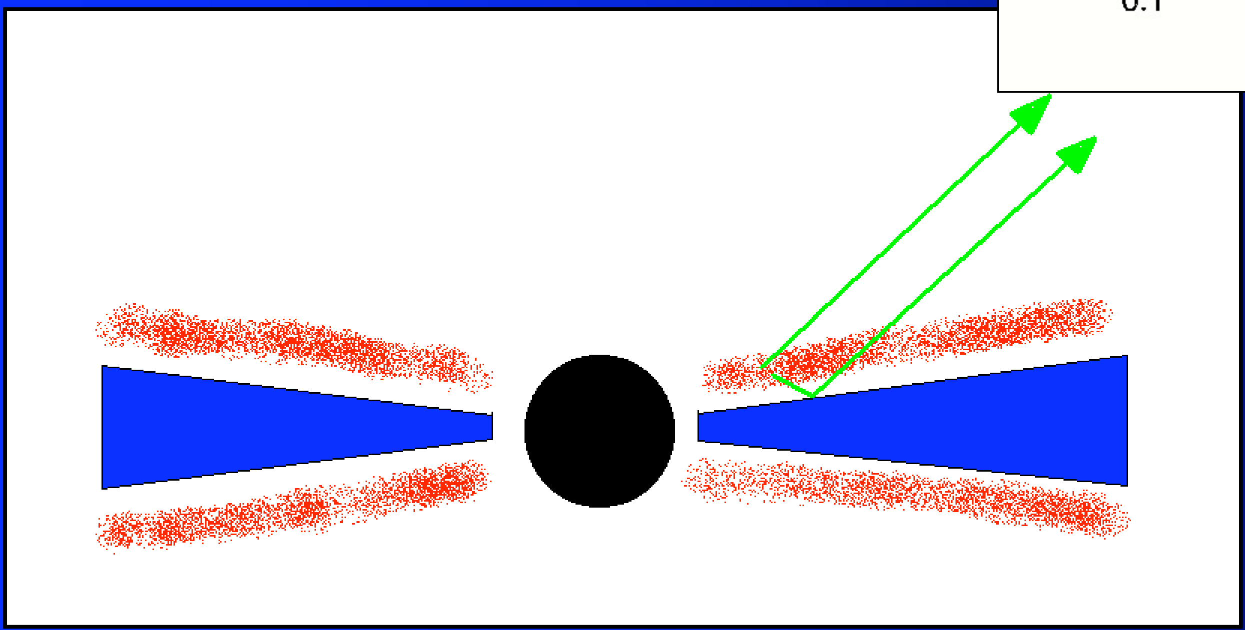


David Ballantyne

Also see

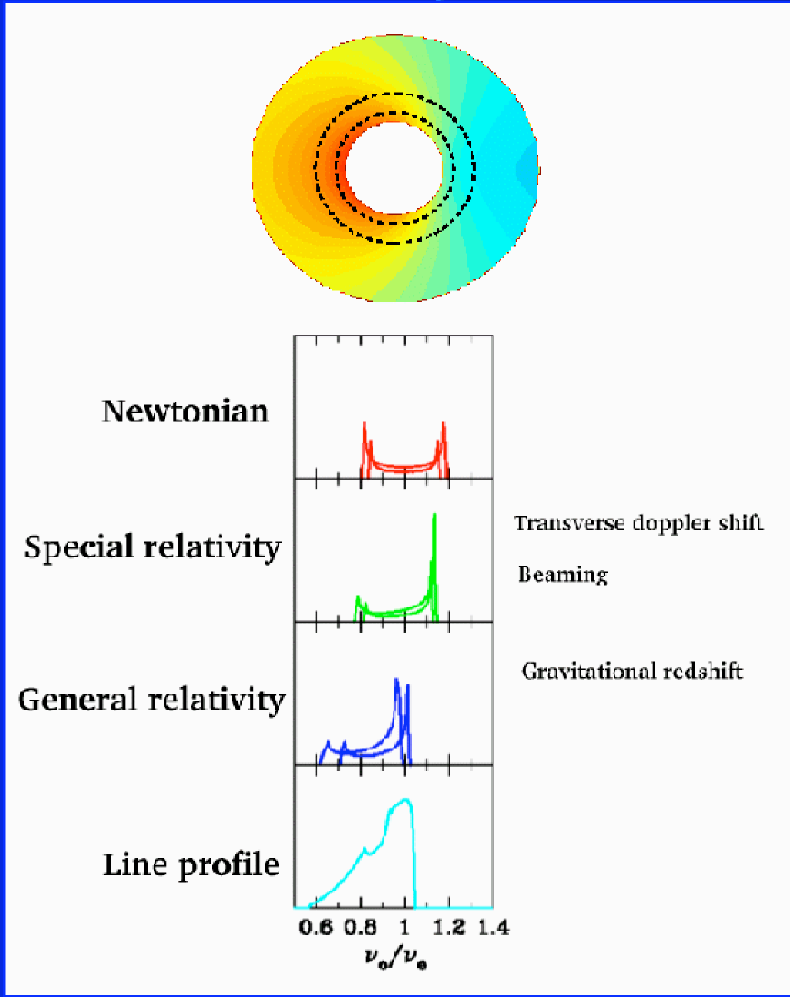
- George & Fabian (1991)
- Matt et al. (1991)
- Reynolds (1996)
- Nayakshin & Kallman (2000)





Relativistic effects imprint characteristic profile on sharp spectral features

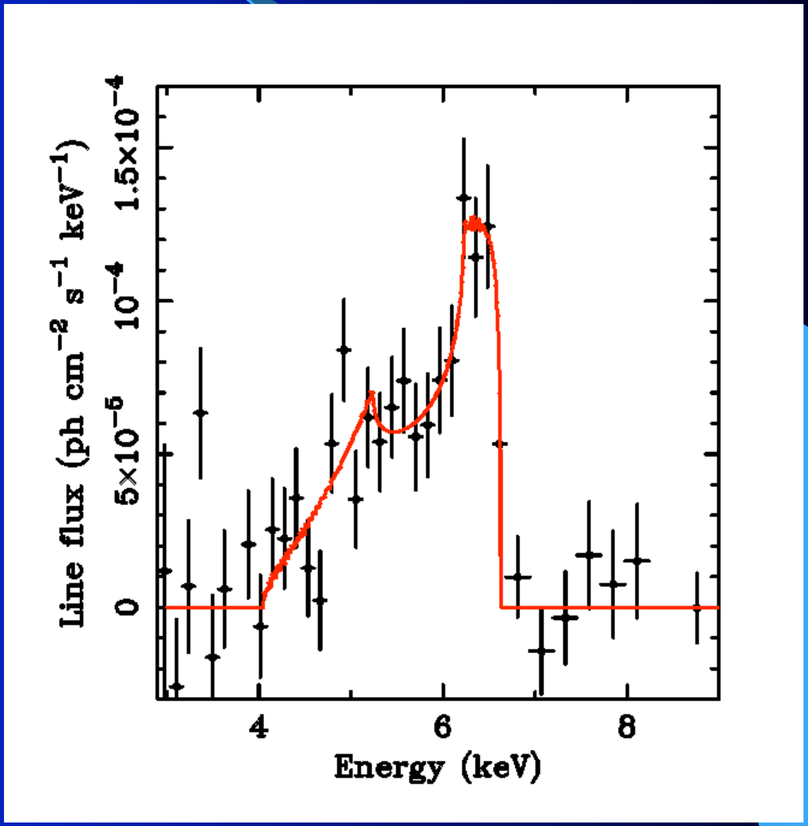
First calculations of line profiles by **Fabian et al. (1989); Laor (1991)**



II : The AGN MCG-6-30-15

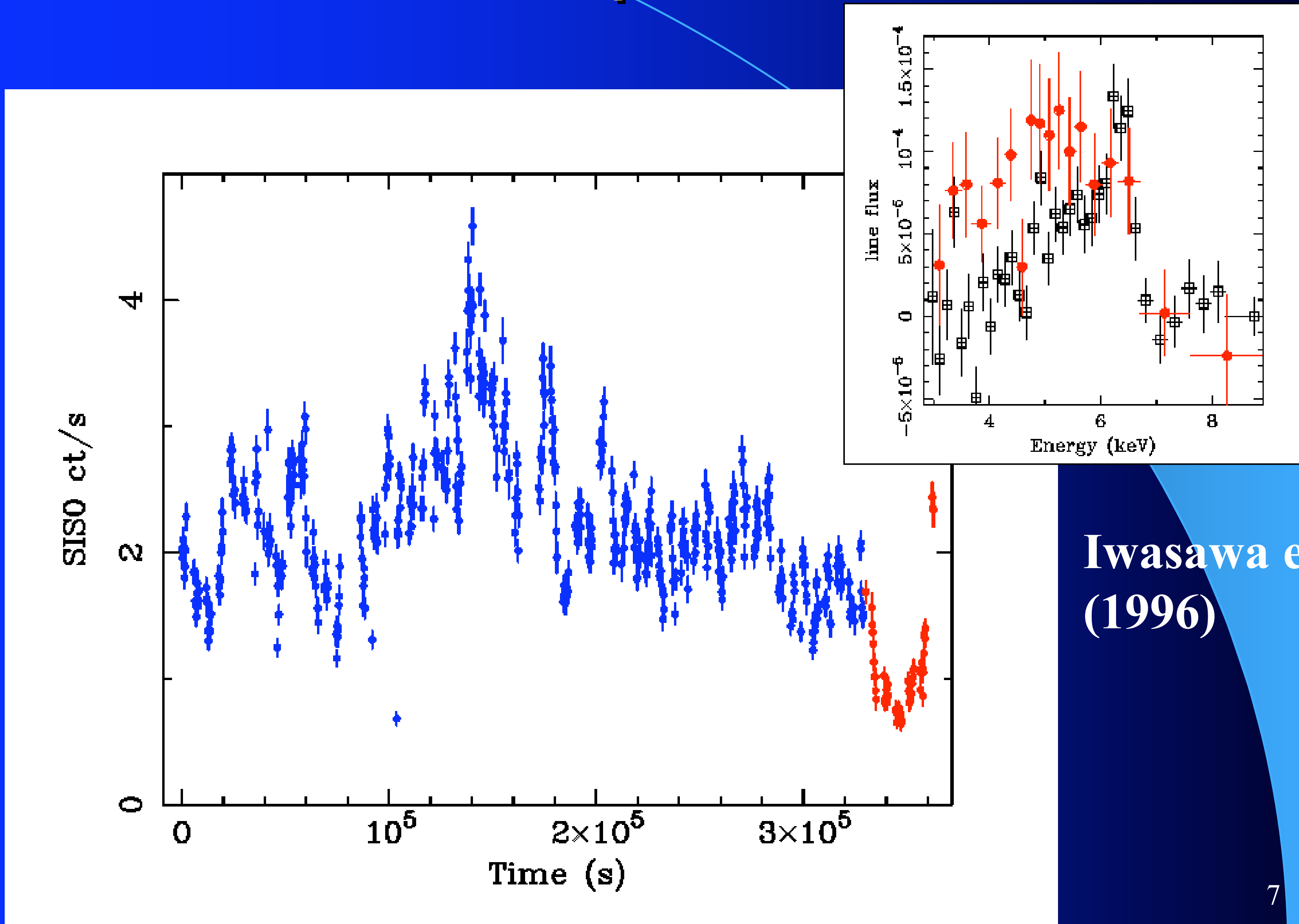
The classic relativistic disk line

- X-ray reflection first found by EXOSAT & Ginga (Nandra et al. 1989; Pound et al. 1990)
- First relativistic broad iron line found by ASCA
  - Consistent with a disk extending to the ISCO of a non-rotating BH
  - Some of the most direct evidence for a supermassive black hole in any source
  - A **ROBUST** FEATURE! (Fabian et al. 1995)



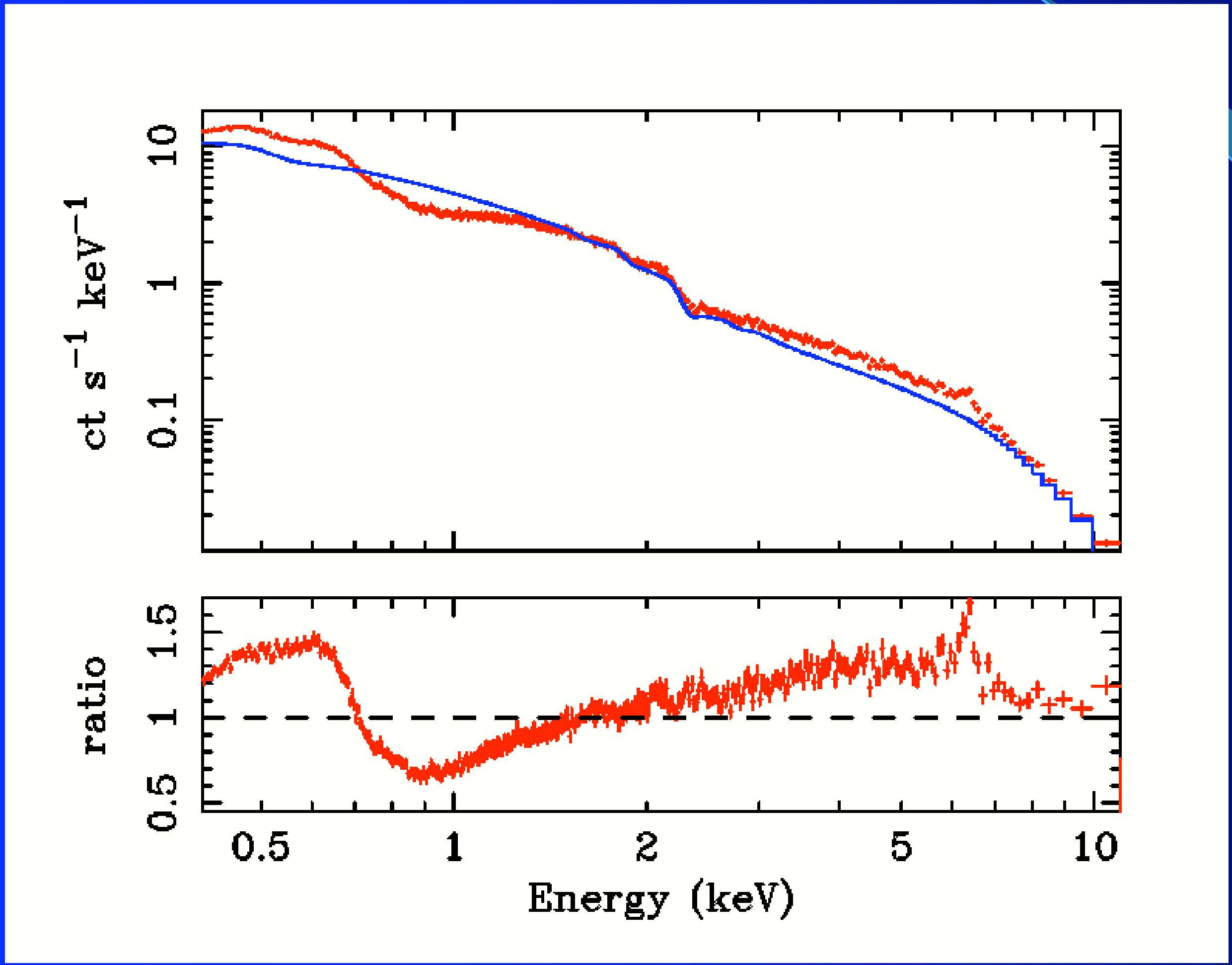
Tanaka et al. (1995)

The "Deep Minimum"



Iwasawa et al. (1996)

June-2000 XMM-Newton observation of MCG-6-30-15

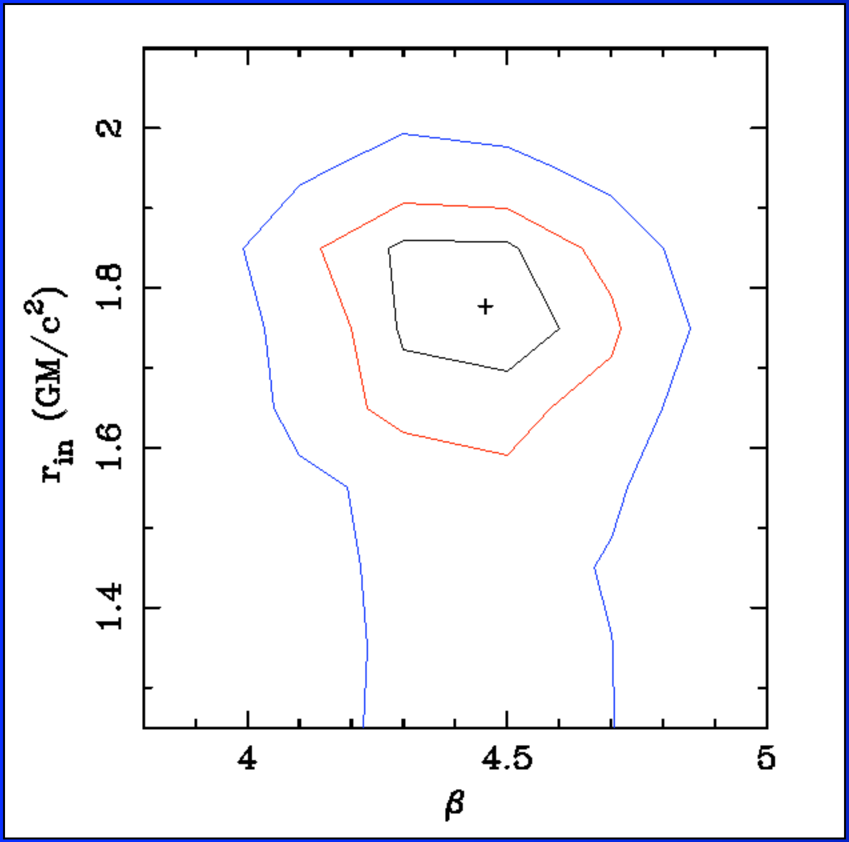


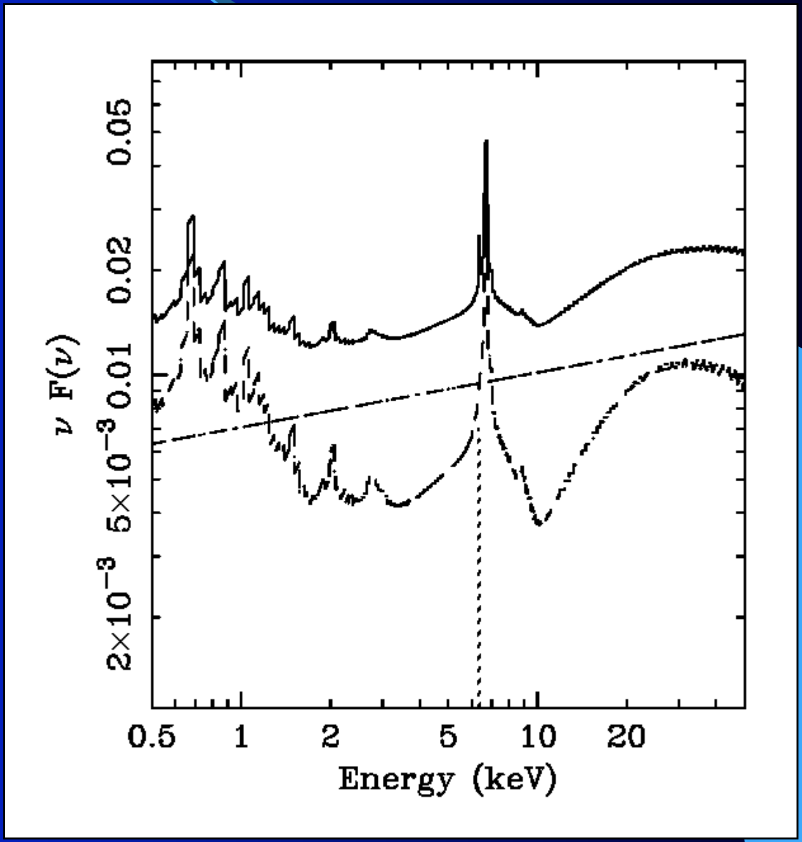
Power-law fit

DEEP MINIMUM STATE!

Disk emissivity…

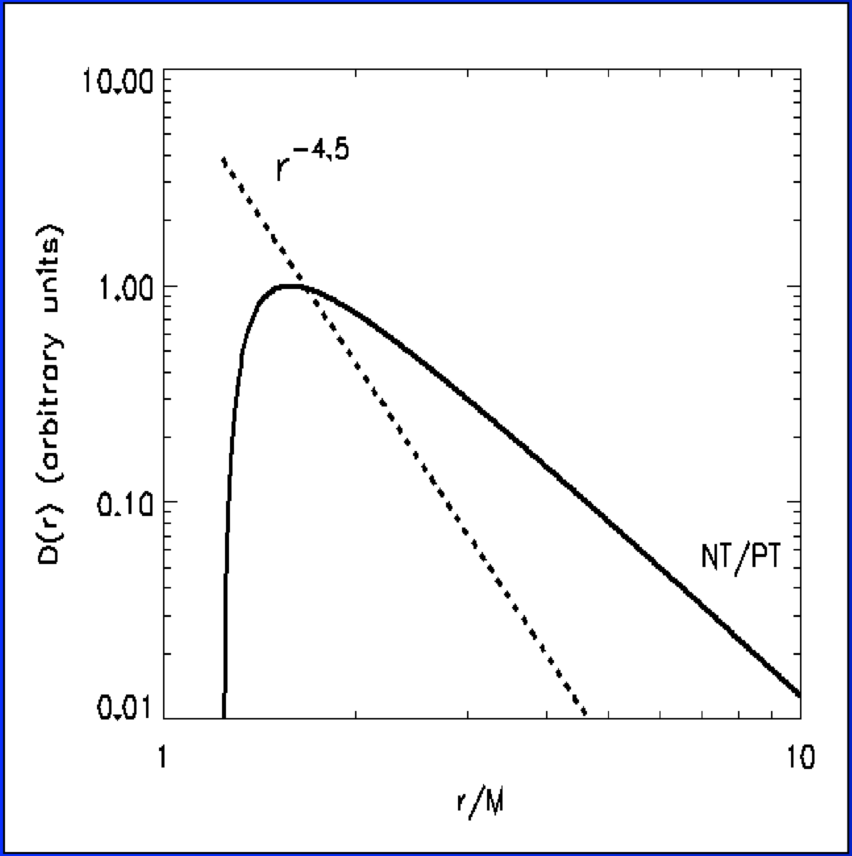
$\varepsilon \propto r^{-\beta}$

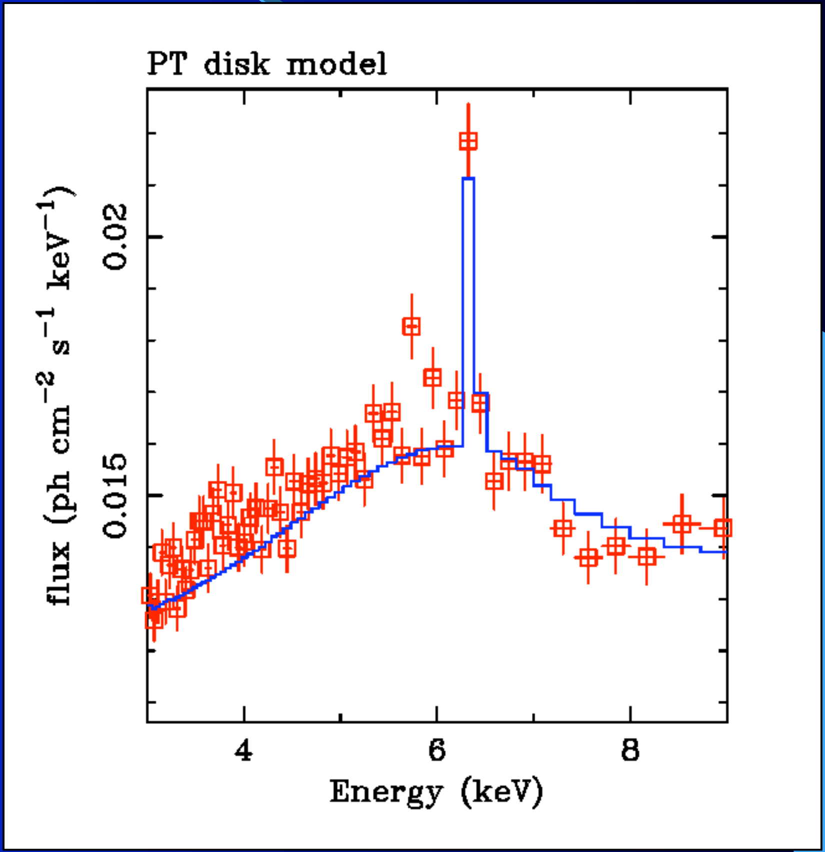




Wilms, Reynolds et al. (2001)
Reynolds et al., in prep.

Inconsistent with "standard" disk models of Novikov, Page & Thorne (PT-disk)



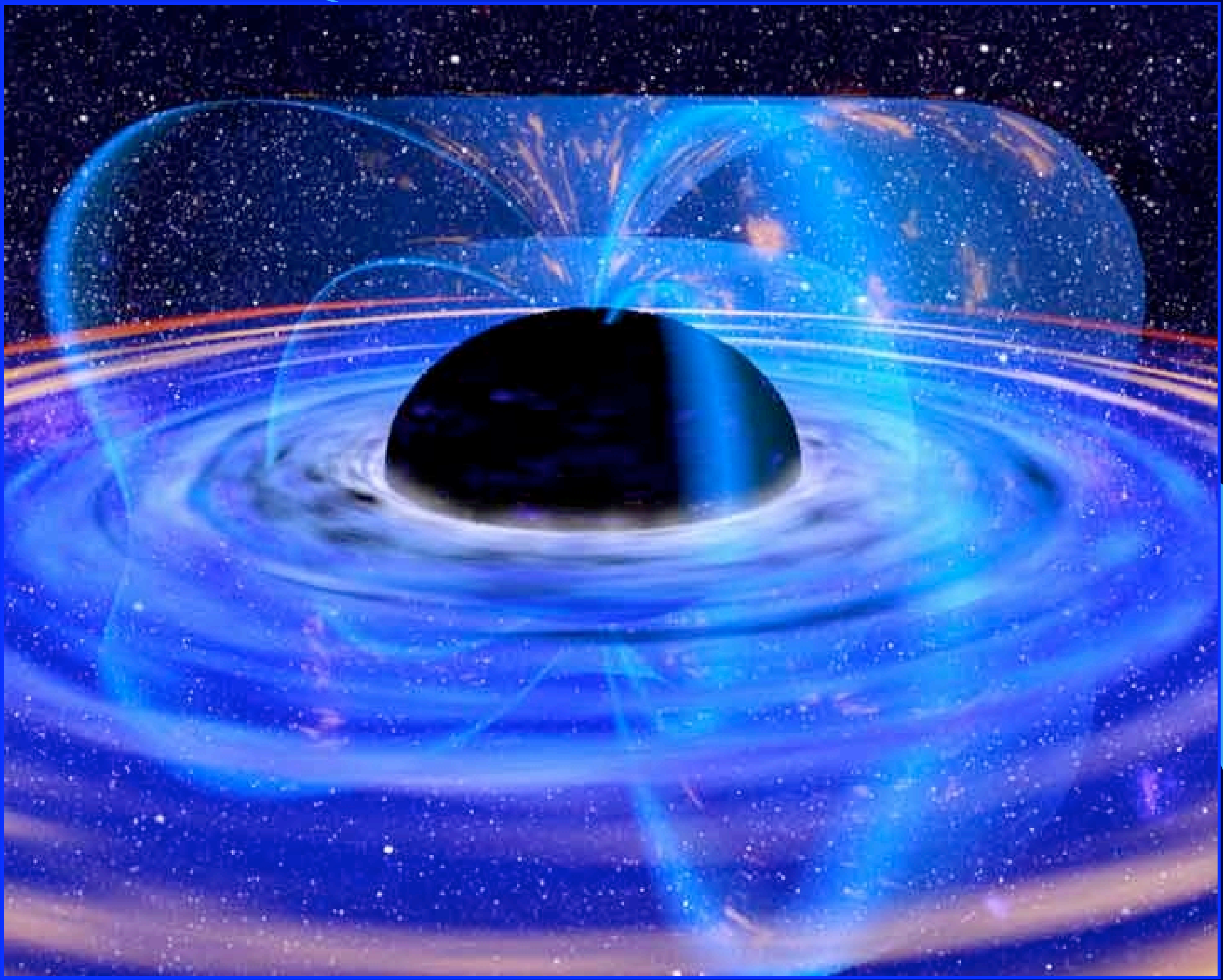


Mismatch $\Rightarrow \Delta\chi^2 \approx 90$

What's going on?

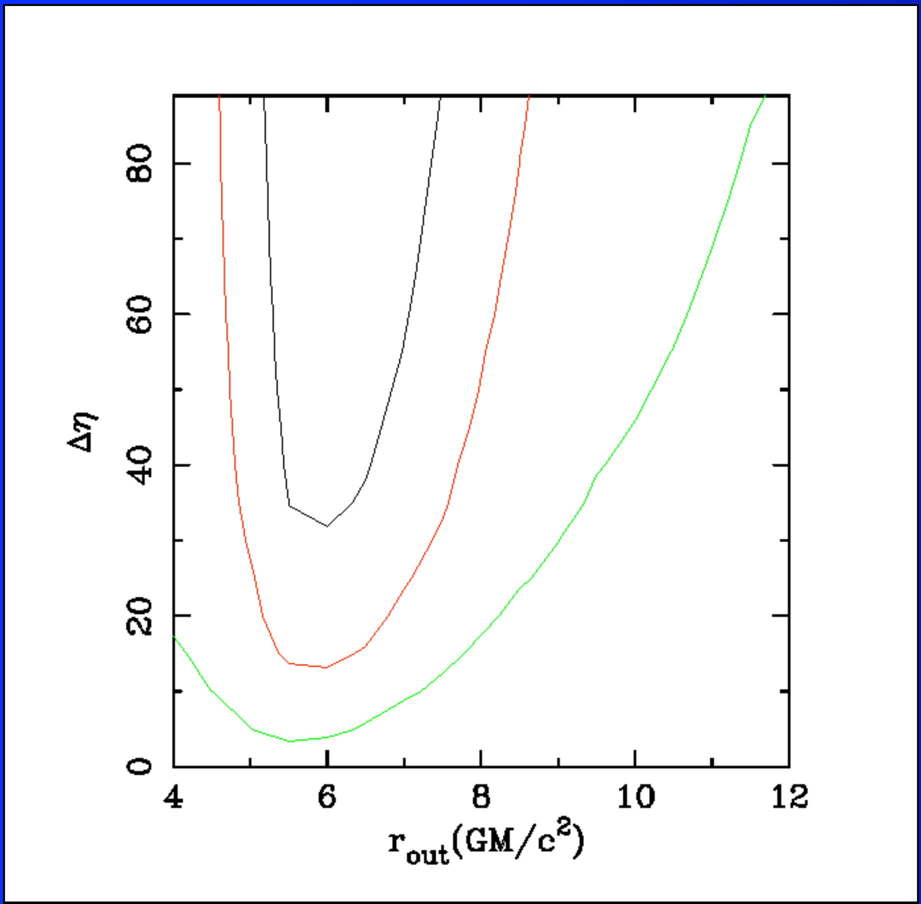
- X-ray emission/reflection does not track total dissipation…
  - Suppose X-ray emission is zero beyond $r=r_{out}$
  - With PT-disk, data require $r_{out}<6GM/c^2$
  - Problems with X-ray/Bolometric ratio…
  - Alternative : vertically displaced source (Martocchia & Matt 2002; Fabian & Vaughan 2003)

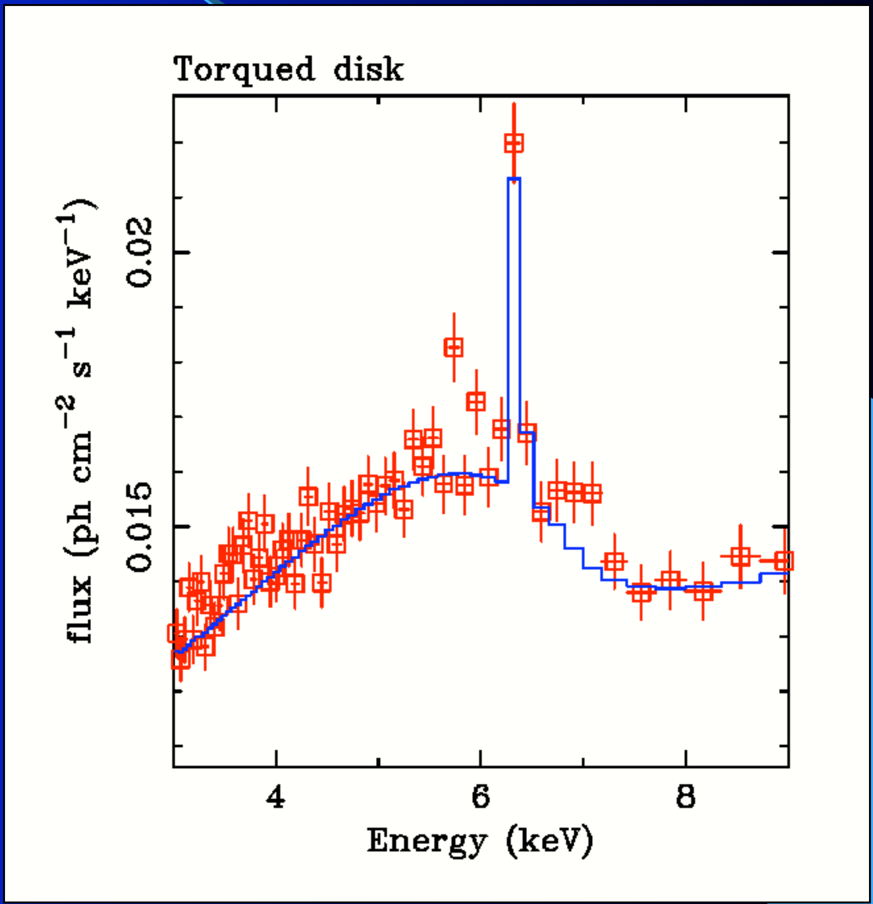
- PT-disk is incorrect… could be torqued at inner edge
  - Gammie 1999; Agol & Krolik 2000; Merloni & Fabian 2003
  - Torque due to magnetic connection between disk and plunging-region or rotating black hole…
  - Possibility for extracting spin-energy of black hole
  - **See poster by Garofalo & CSR**



NASA/Dana Berry

Torqued accretion disks

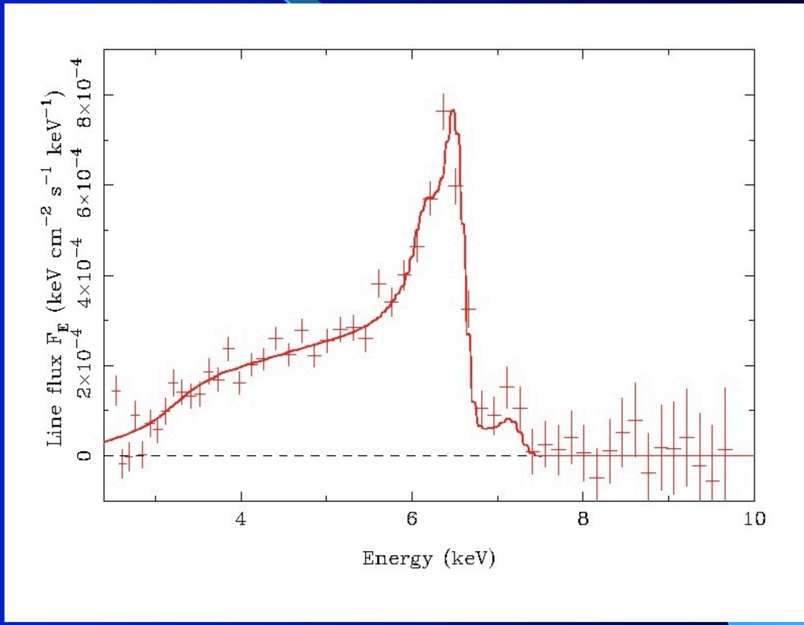




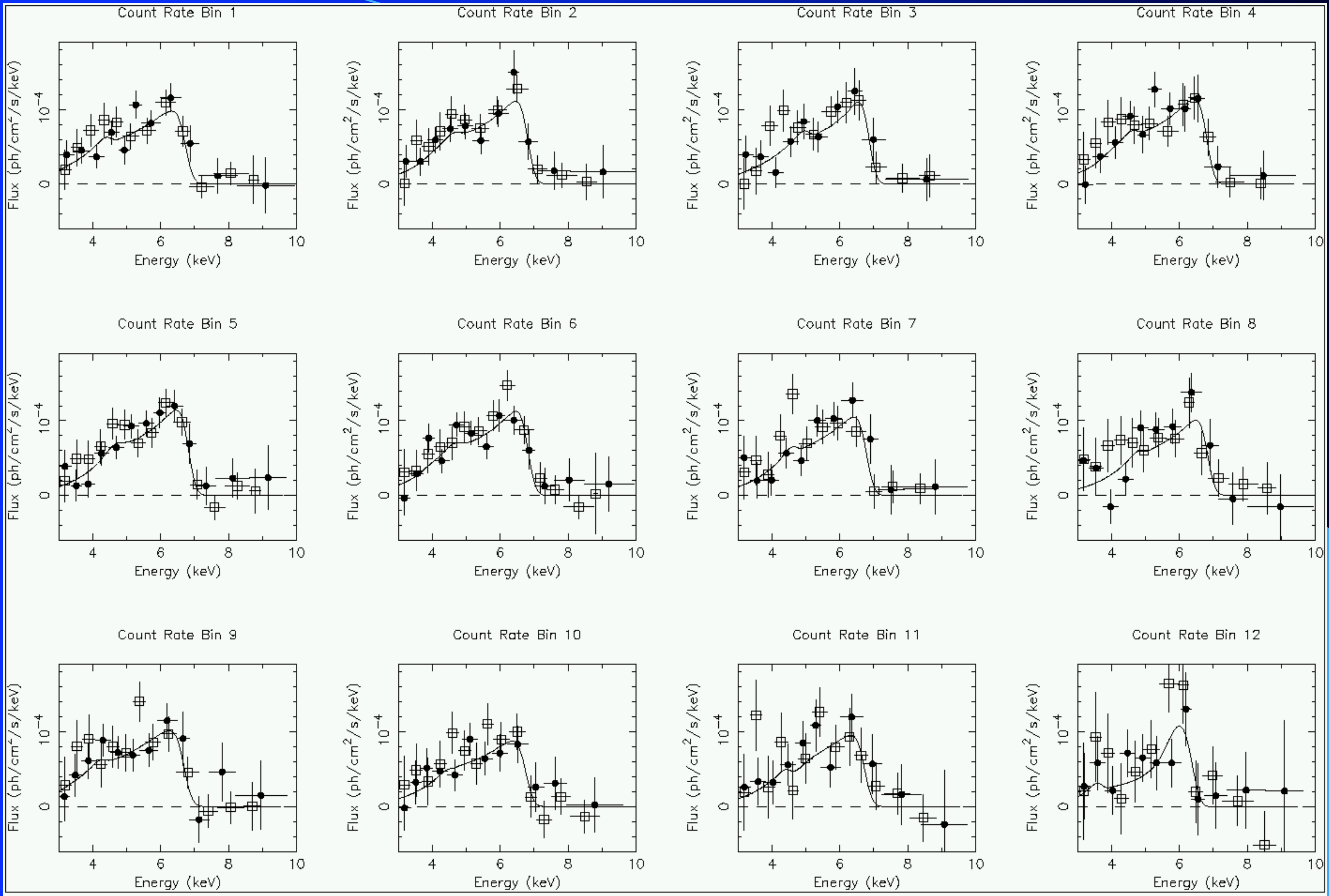
CSR et al. (2003, in prep.)

Comparison with the 320ks XMM observation of MCG-6-30-15

- Deep look at MCG-6-30-15
  - Caught source in higher-flux state (not Deep Minimum)
  - Very high S/N iron line
  - Disk emission more distributed, but very broad red wing still present
- Lack of flux-correlated line variability…
  - Spectrum decomposes into constant "reflection-dominated" spectrum, and variable power-law.

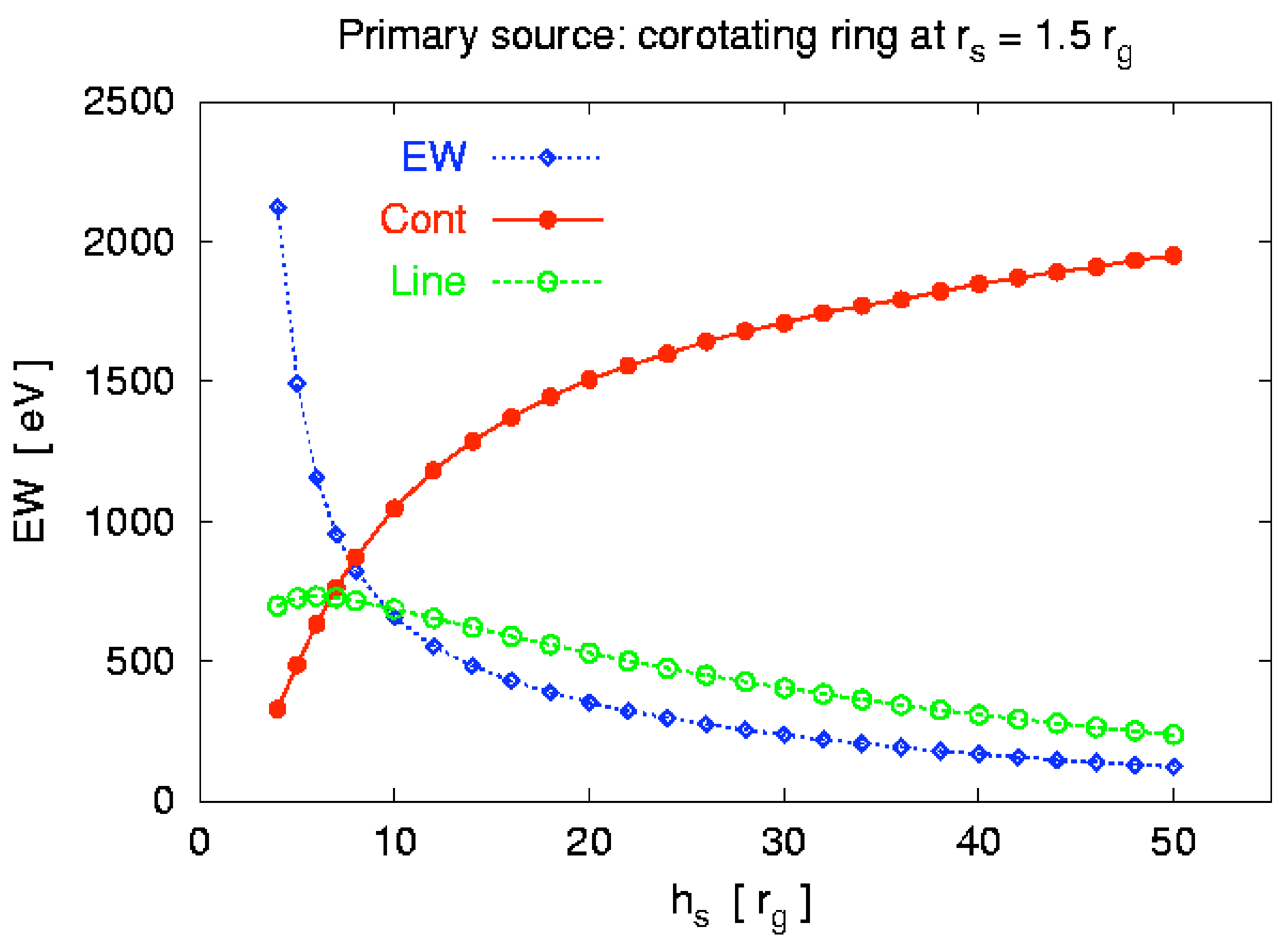


Fabian et al. (2002)
Fabian & Vaughan (2003)



Also… see RXTE analyzes of Chiang, CSR et al. (2000), CSR (2000) Lee et al. (2000)

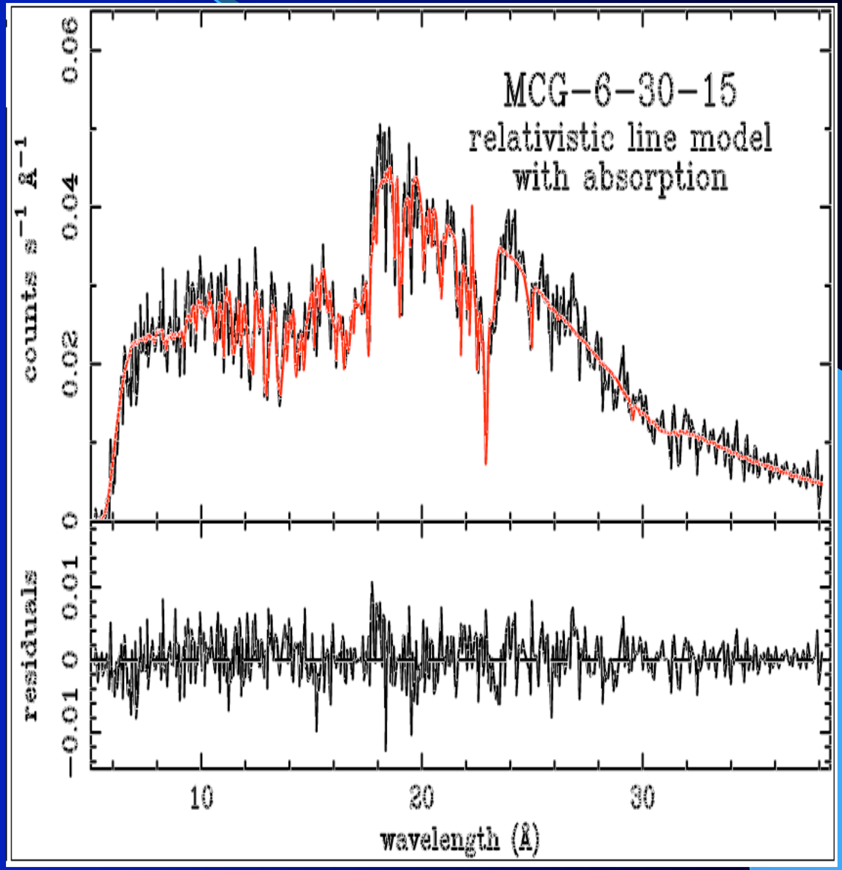
MCG-6-30-15 (ASCA)
Shih et al. (2001)



Minuitti et al.

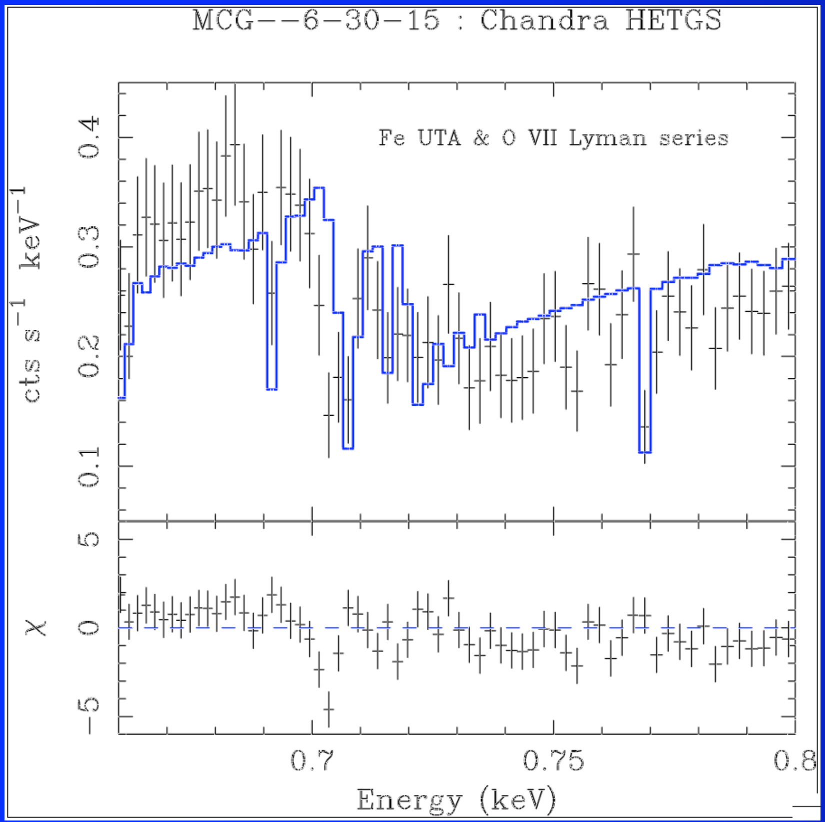
A dusty warm absorber or soft X-ray lines from a relativistic disk

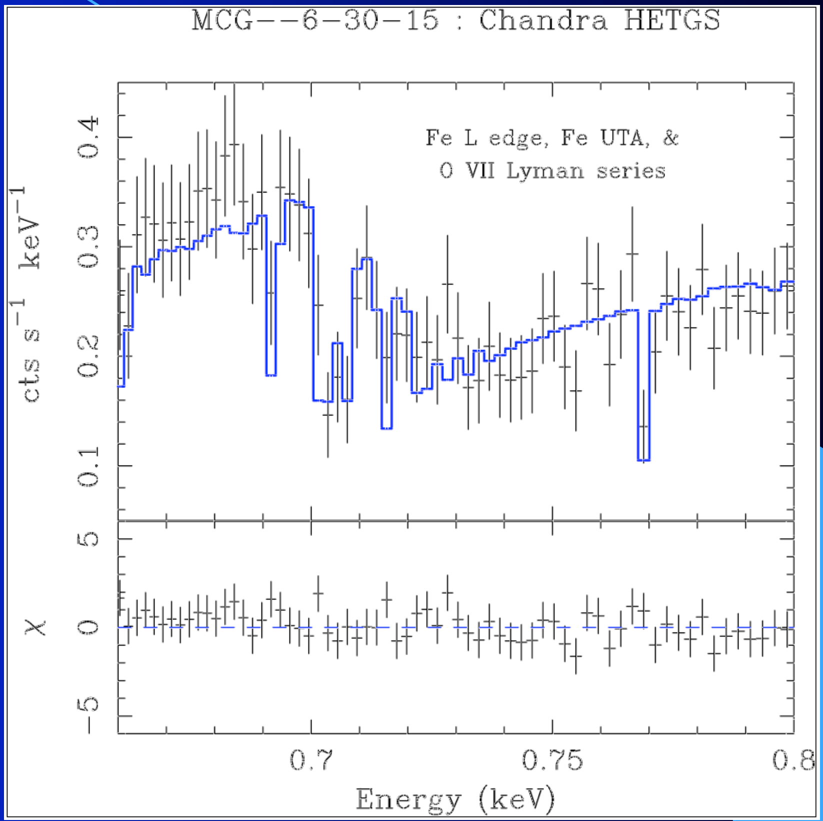
- Arguments against pure warm absorber model;
  - Simple oxygen edges seem are absent?
  - Resonance absorption lines of oxygen are weak
- Relativistic line model;
  - Relativistic emission lines of OVIII, NVII and CVI…
  - … plus some ionized absorption
- But… WA is dusty! Can this affect the spectral arguments?



Branduardi-Raymont et al. (2001); Sako et al. (2002)

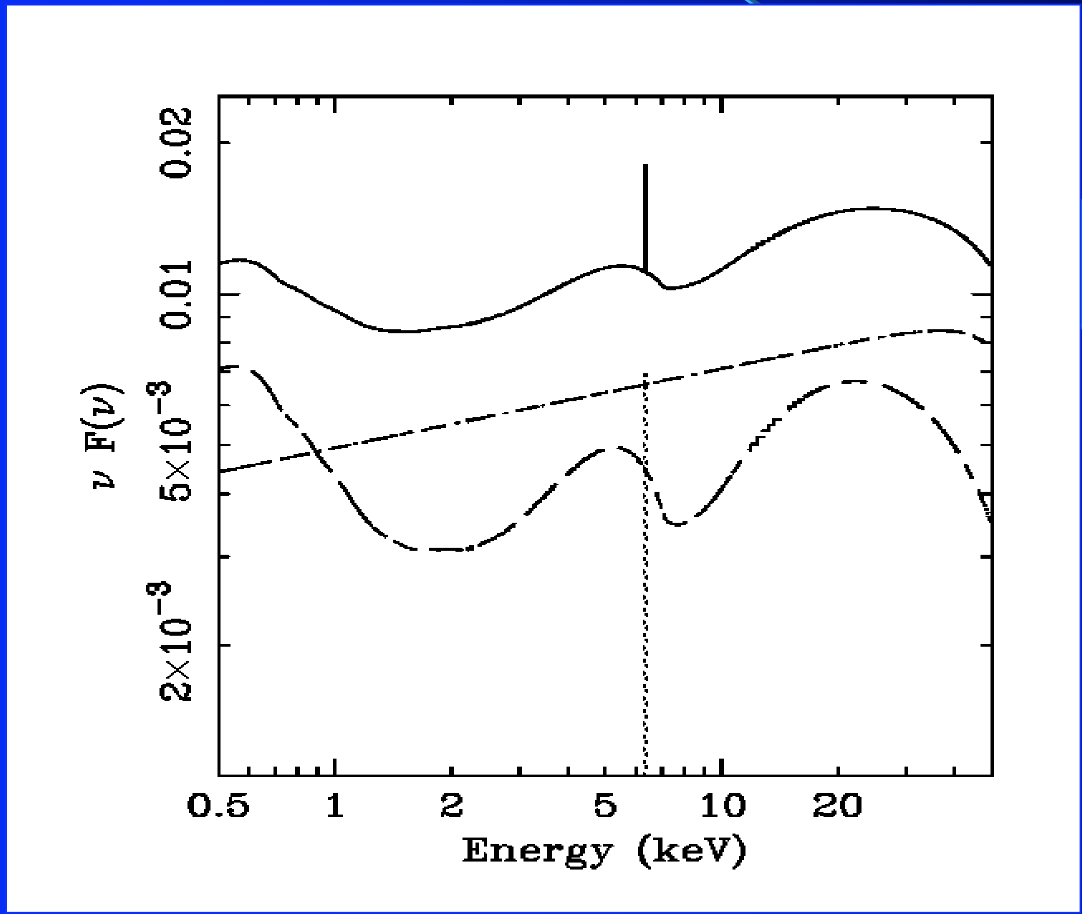
Still subject of debate…





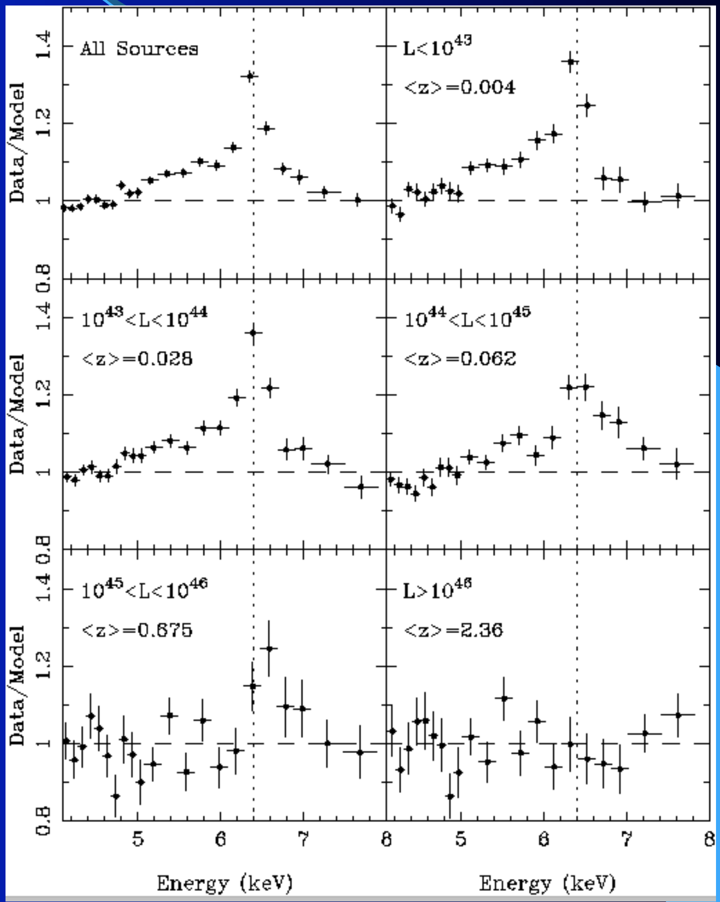
Lee et al. (2003)

Remember that underlying soft continuum may be rather bumpy (from reflection continuum)!



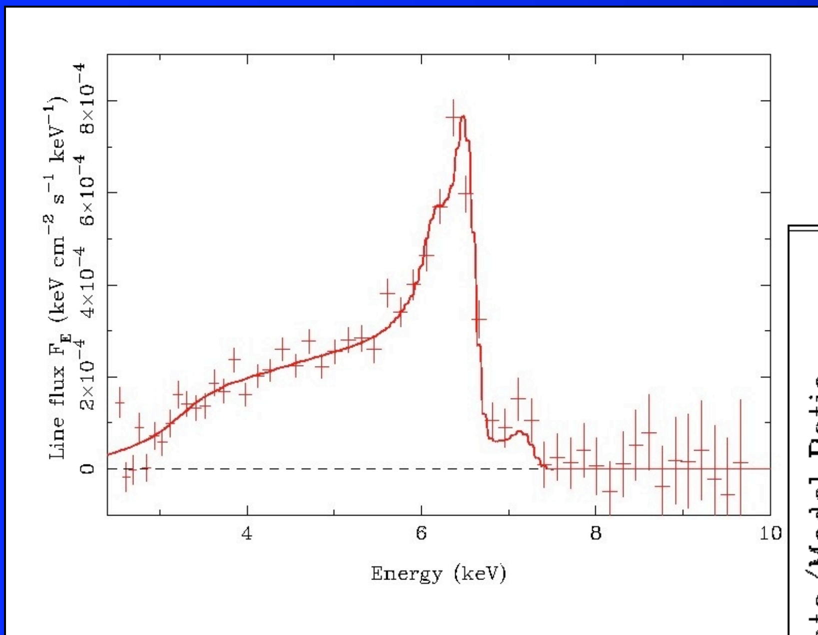
II : Are disk signatures generic?

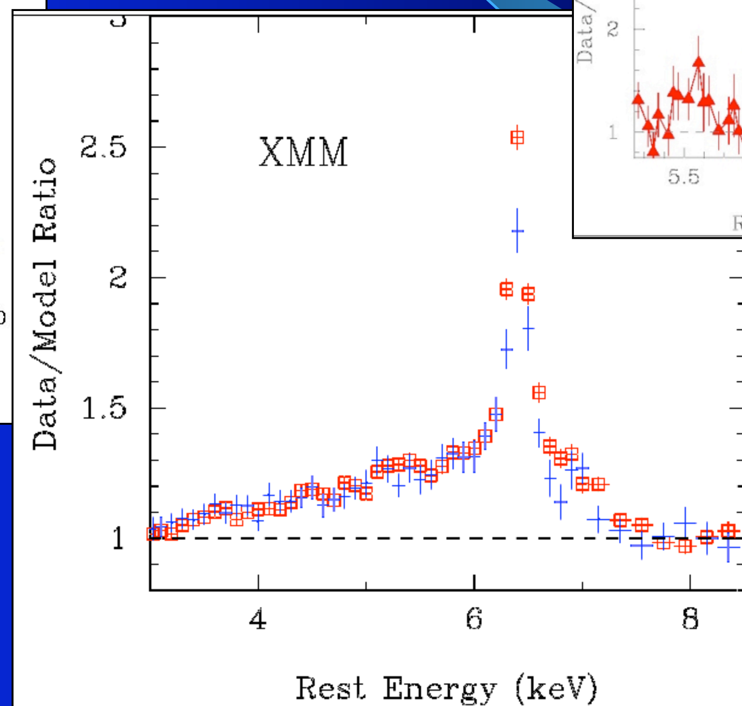
- Results from ASCA
  - Broad lines generic in Seyfert galaxies
  - Became weaker in high-L AGN.
  - Also weak in low-L AGN
  - Very promising and “clean” probe of accretion disks and black hole physics in most generic AGN!
- Situation become more complex with XMM observations

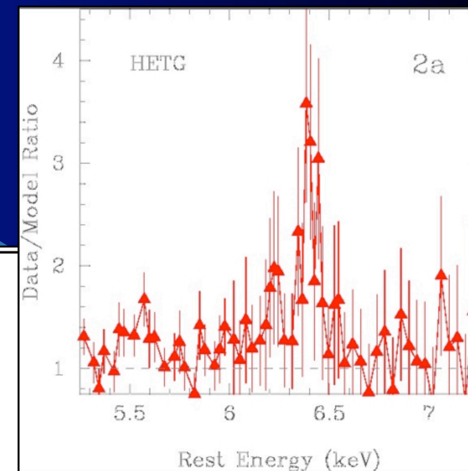


Nandra et al. (1997)

The iron-clad cases







MCG-6-30-15

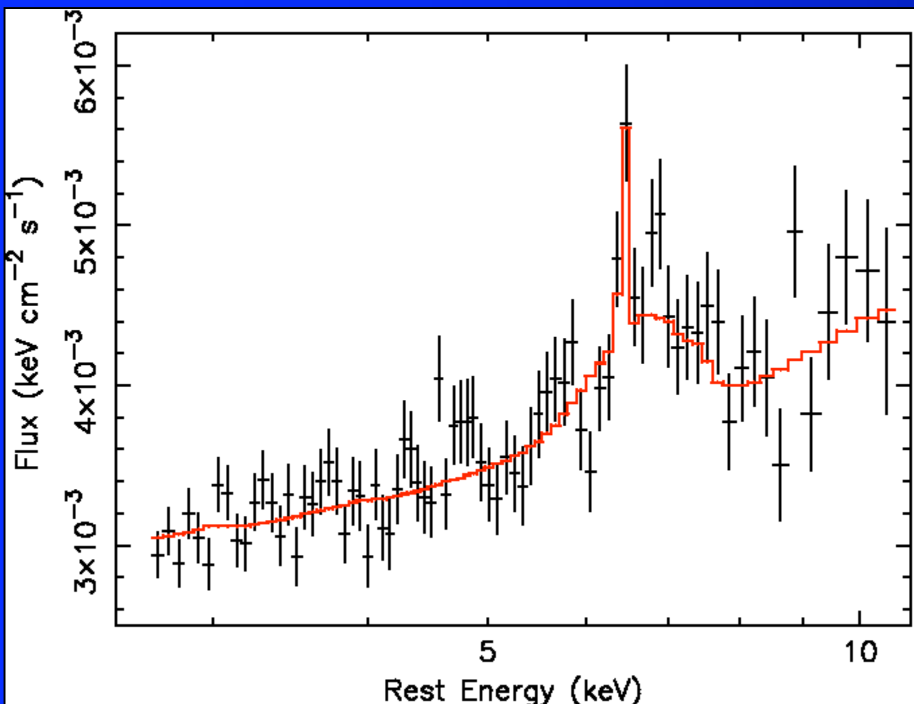
Wilms et al. (2001)
Fabian et al. (2002)
Reynolds et al. (2003)

NGC3516

Turner et al. (2002)

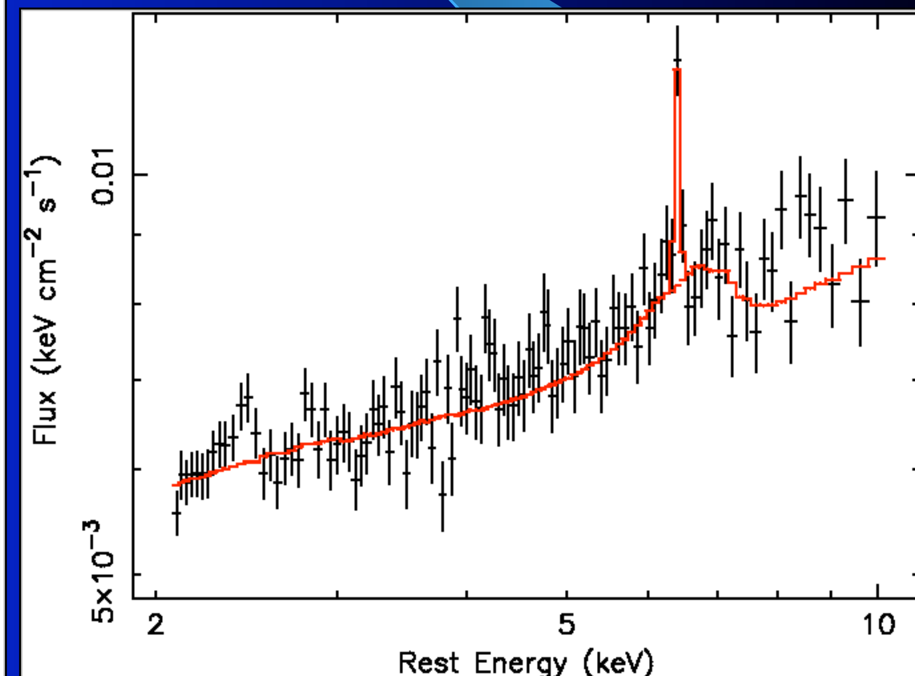
Direct detection of ionized disks

Mrk509
(high-L Seyfert)



Reeves et al. (2001)

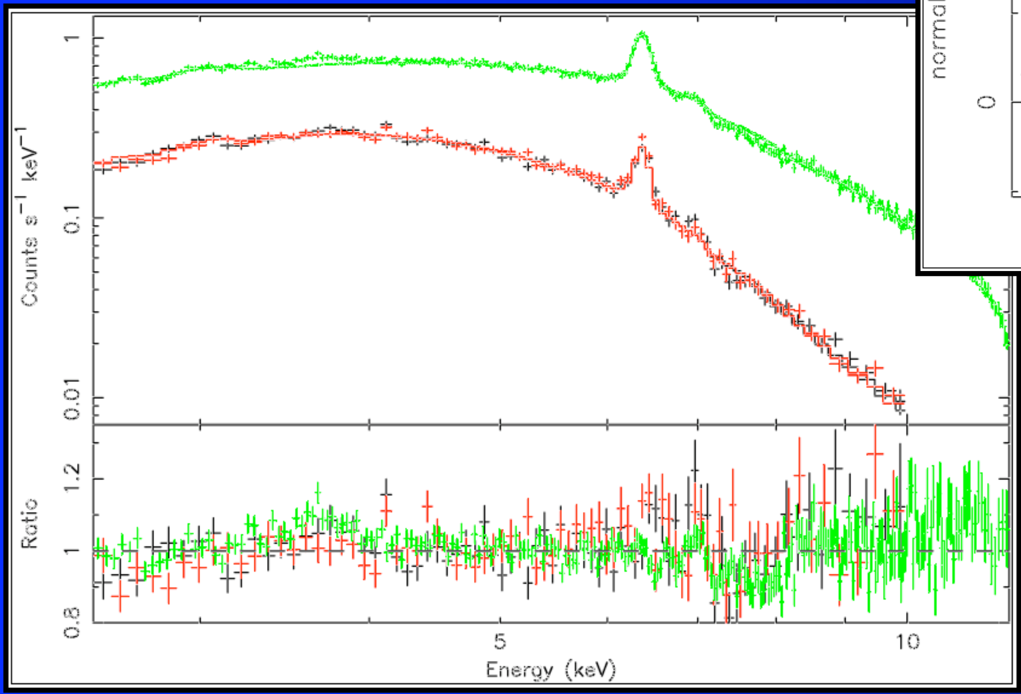
Mrk205
(low-L quasar)

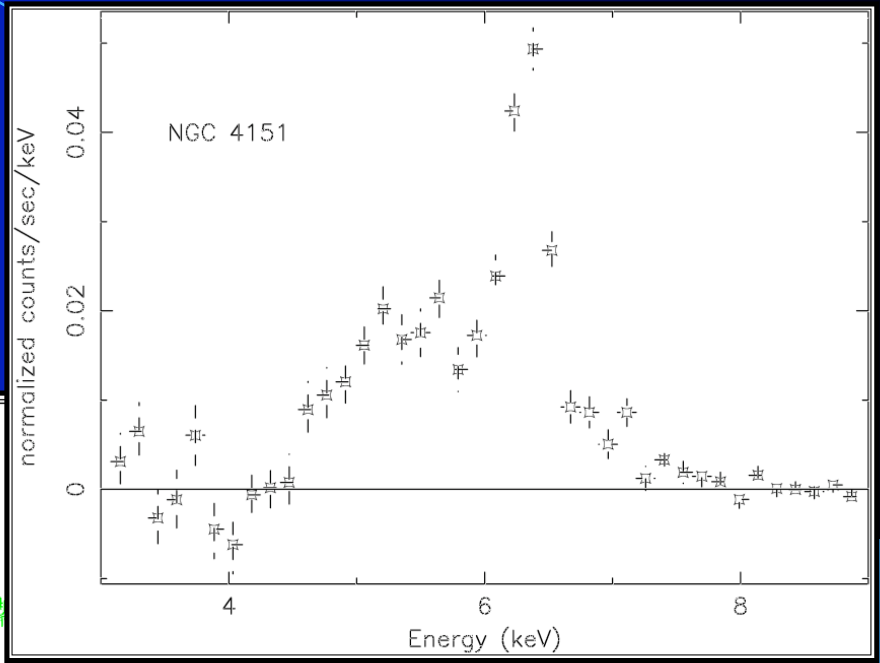


Pounds et al. (2001)

NGC 4151

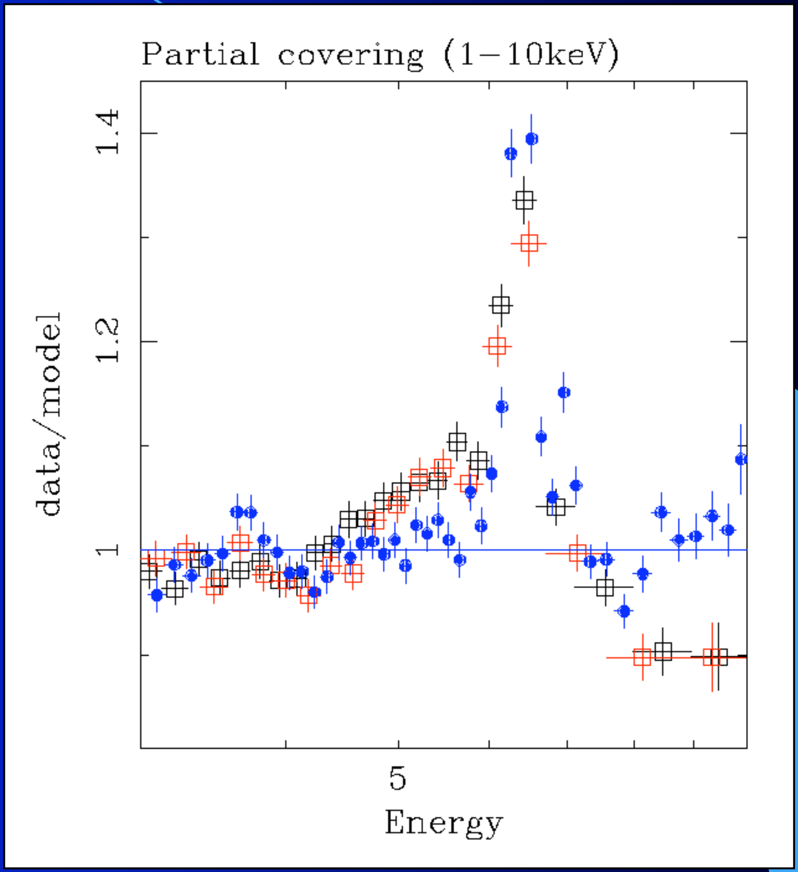
XMM-Newton
(Schurch et al. 2002)





ASCA
Wang et al. (1999,2002)

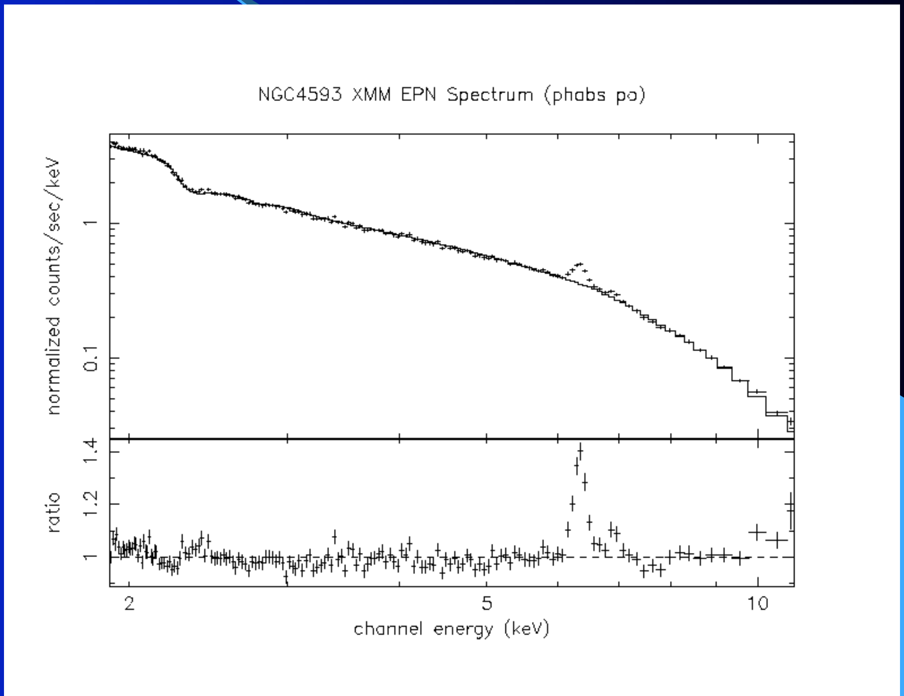
- Comparison of ASCA and XMM data…
  - Broad line substantially weaker during XMM observation
  - Very strong line of Wang et al. probably artifact of poor continuum subtraction
  - Need to be very careful about modelling absorption! (Schurch et al. 2002)



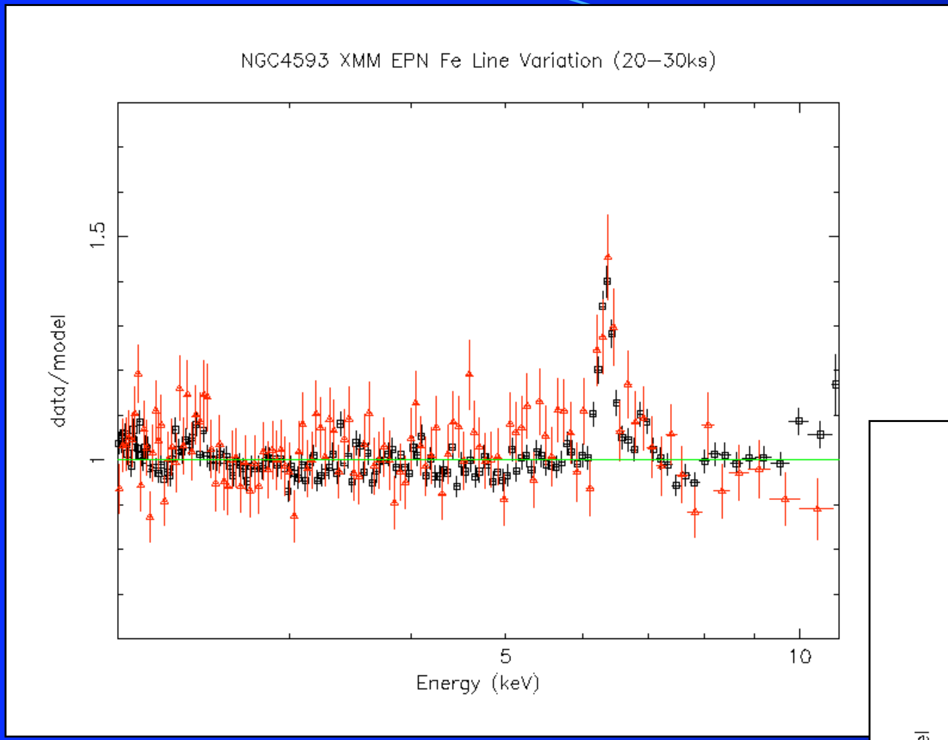
Koeckert & Reynolds

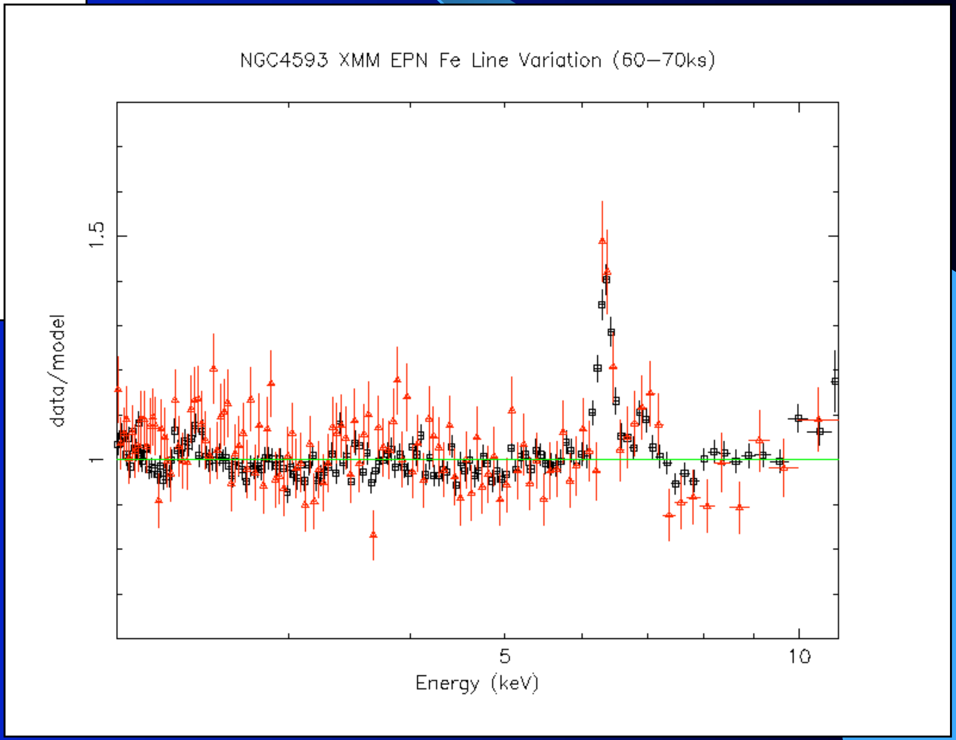
NGC 4593

- Somewhat similar AGN to MCG-6-30-15
  - Radio-quiet AGN
  - Similar BH mass and luminosity
  - Rapidly variable in X-rays
  - X-ray warm absorber
- July 2002 campaign… ESO, STIS, XMM, RXTE
- Preliminary XMM results:
  - No obvious disk signatures
  - Hard (not impossible!) to smear/ionize features away



Brenneman & CSR





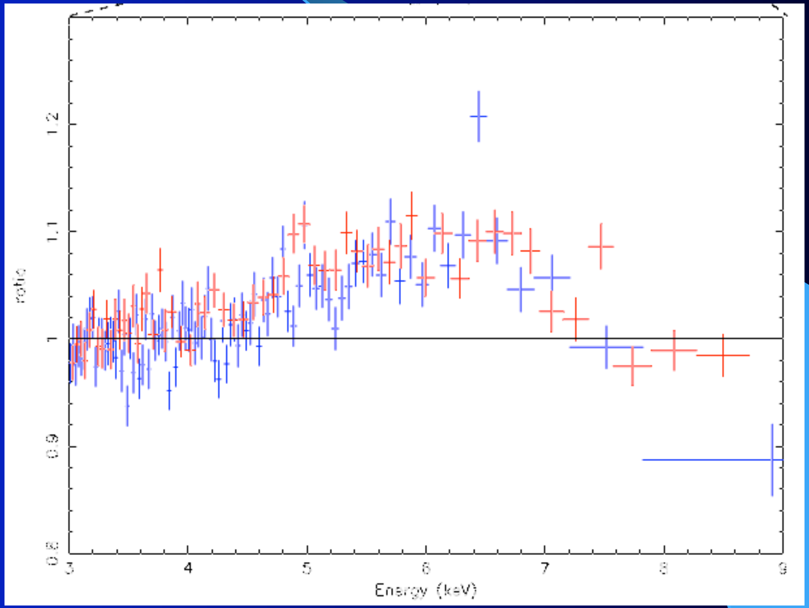
Brenneman & CSR

The search for disks…

- Disk features <u>should</u> be present in X-ray spectra of active sources!
- Careful analysis is required:
  - Modeling the continuum properly is crucial
  - … <u>but</u> you cheat yourself if you include arbitrary (unphysical) continuum components!
- Also have to account for:
  - Strong ionization of disk surface
  - Extremely strong relativistic smearing (e.g. MCG-6)
  - Dramatic variability of spectral features (Are XMM observations too short to see "well-behaved" features?)

IV: Disk signatures in Galactic Black Hole Binaries

- Studied by Ginga & RXTE (see review by CSR & Nowak 2003)
- Disk signatures hard to study in GBHCs
  - Disk ionization generic
  - Complex continuum
  - Bright; saturated early CCD spectrometers
- Chandra & XMM
  - revealed broad iron lines in Cyg-X1 & XTEJ1650-500
- See talk by Jon Miller…

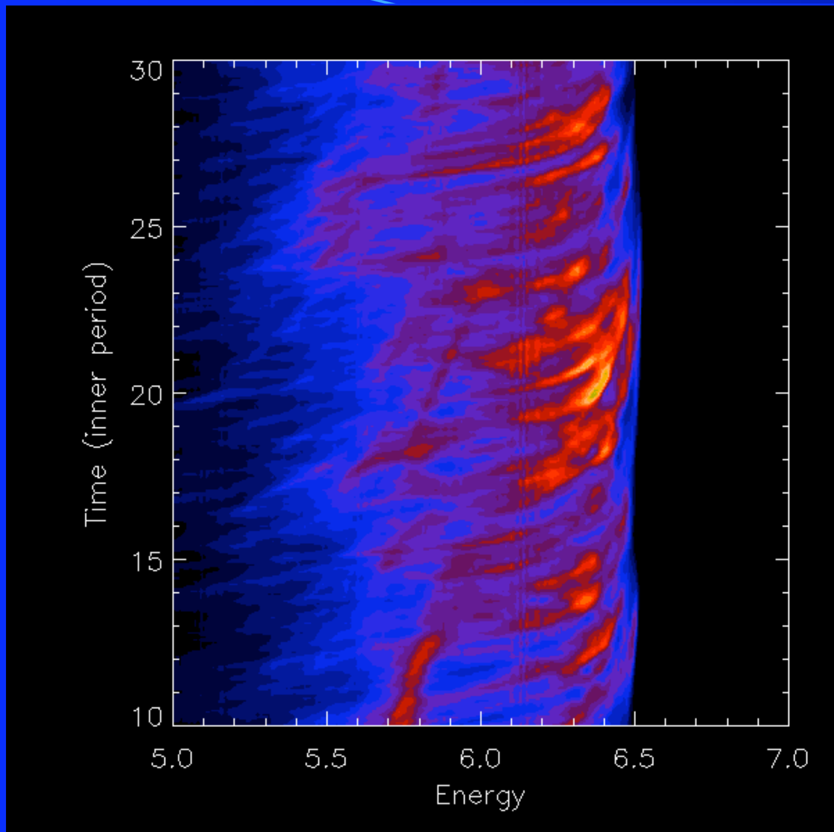


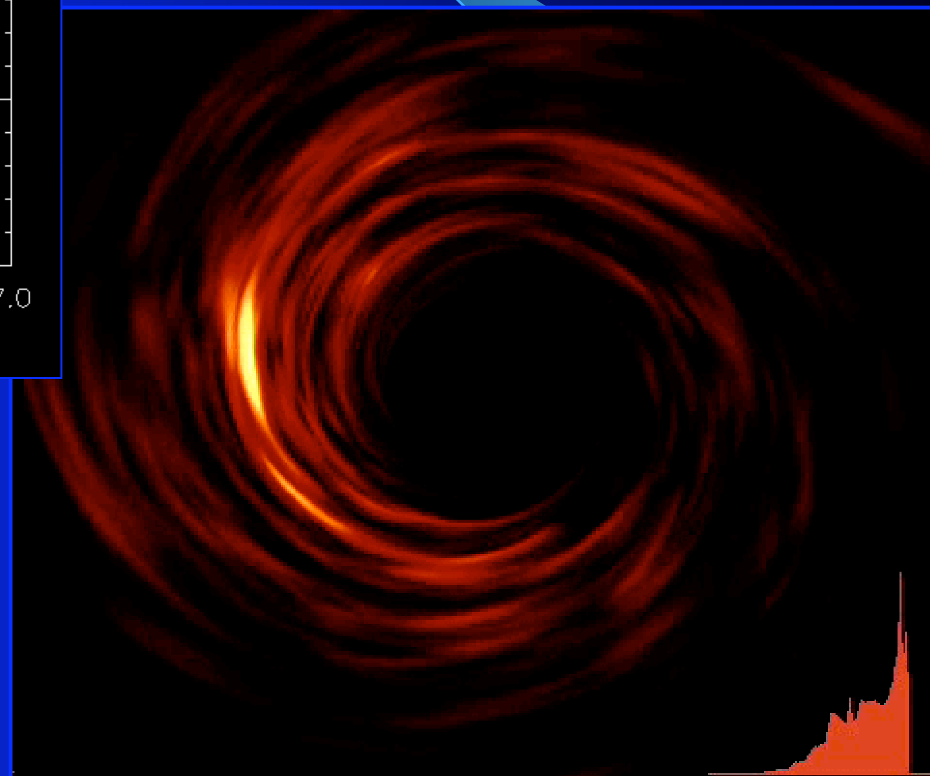
Red: XTEJ1650-500 (XMM-Newton)
Blue : Cygnus X-1 (Chandra)
Miller et al. (2001,2002)

V : Constellation-X studies of BH disk signatures

- High resolution spectroscopy across 0.5-10keV band crucial for disentangling complex systems
- Variability of disk signatures open up new windows on physics of accretion disks and black hole themselves
  - Variability on dynamical timescale $\Rightarrow$ turbulence
  - Variability on light-crossing time $\Rightarrow$ reverberation $\Rightarrow$ space-time geometry

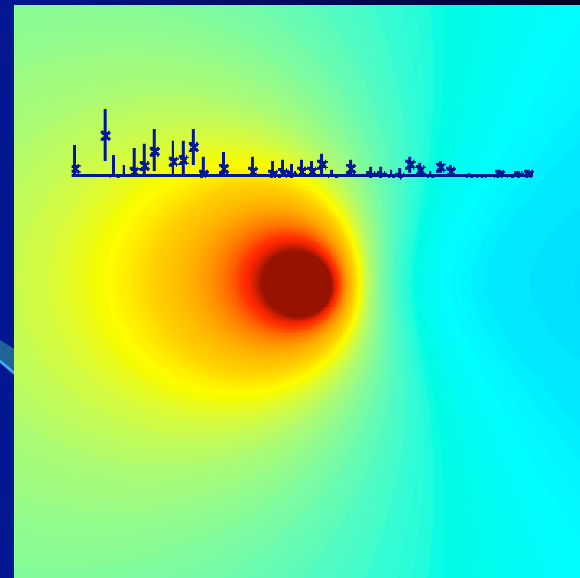
Probe of disk turbulence

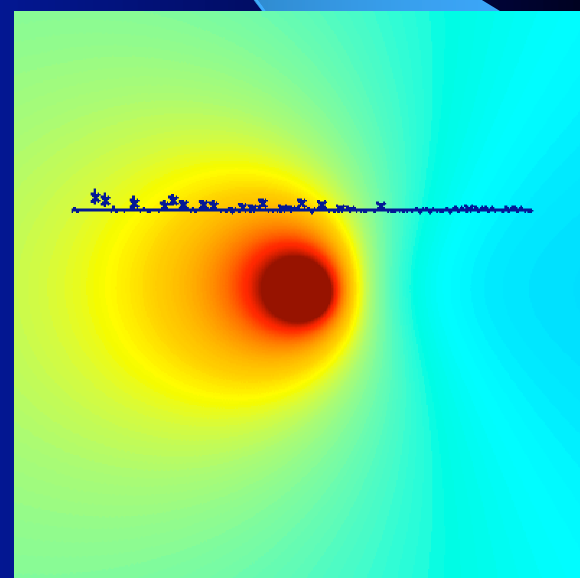




Armitage & Reynolds (2003)

- Reverberation of X-ray flares (CSR et al. 1999)
- Sensitive probe of space-time geometry
  - Get inward and outward propagating X-ray echoes
  - inward propagating echo is purely a relativistic effect $\Rightarrow$ measure spin parameter
- Just within reach of Con-X

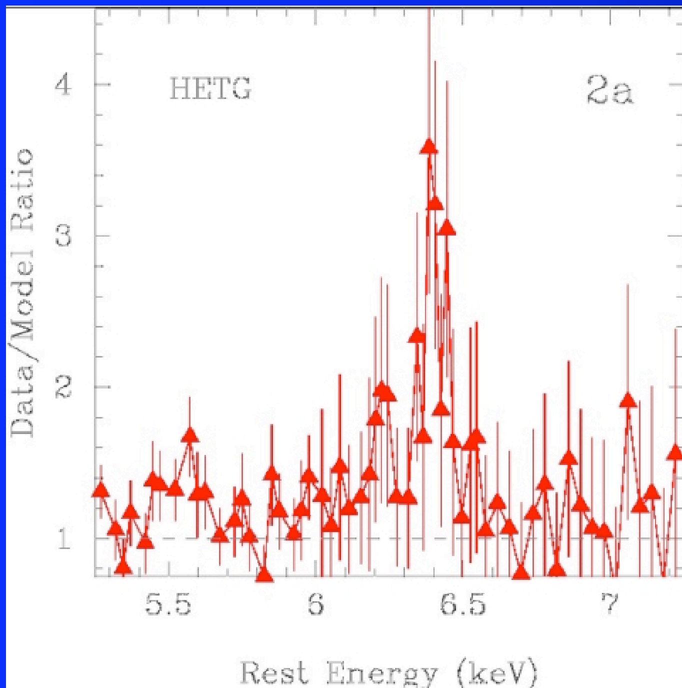




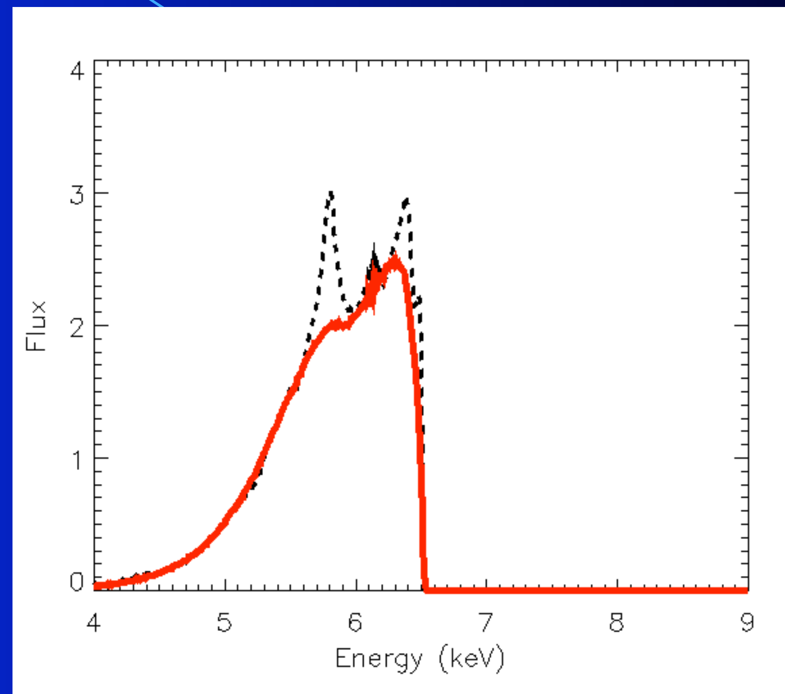
Conclusions

- X-ray spectroscopy can provide powerful probe of relativistic accretion disks
  - Some iron clad and well-studied cases (both AGN and GBHCs)
  - Broad iron lines not as generic as previously thought? Jury still out…
  - Ionization, extreme smearing, variability may all play role in reducing prominence of features.
- Capabilities of Constellation-X crucial for pushing significantly beyond Chandra/XMM era
  - High resolution spectroscopy needed to disentangle complex spectra (esp. characterize absorption)
  - Variability of disk signatures used to probe turbulence and space-time geometry.

Non-axisymmetric structure may have been seen already…

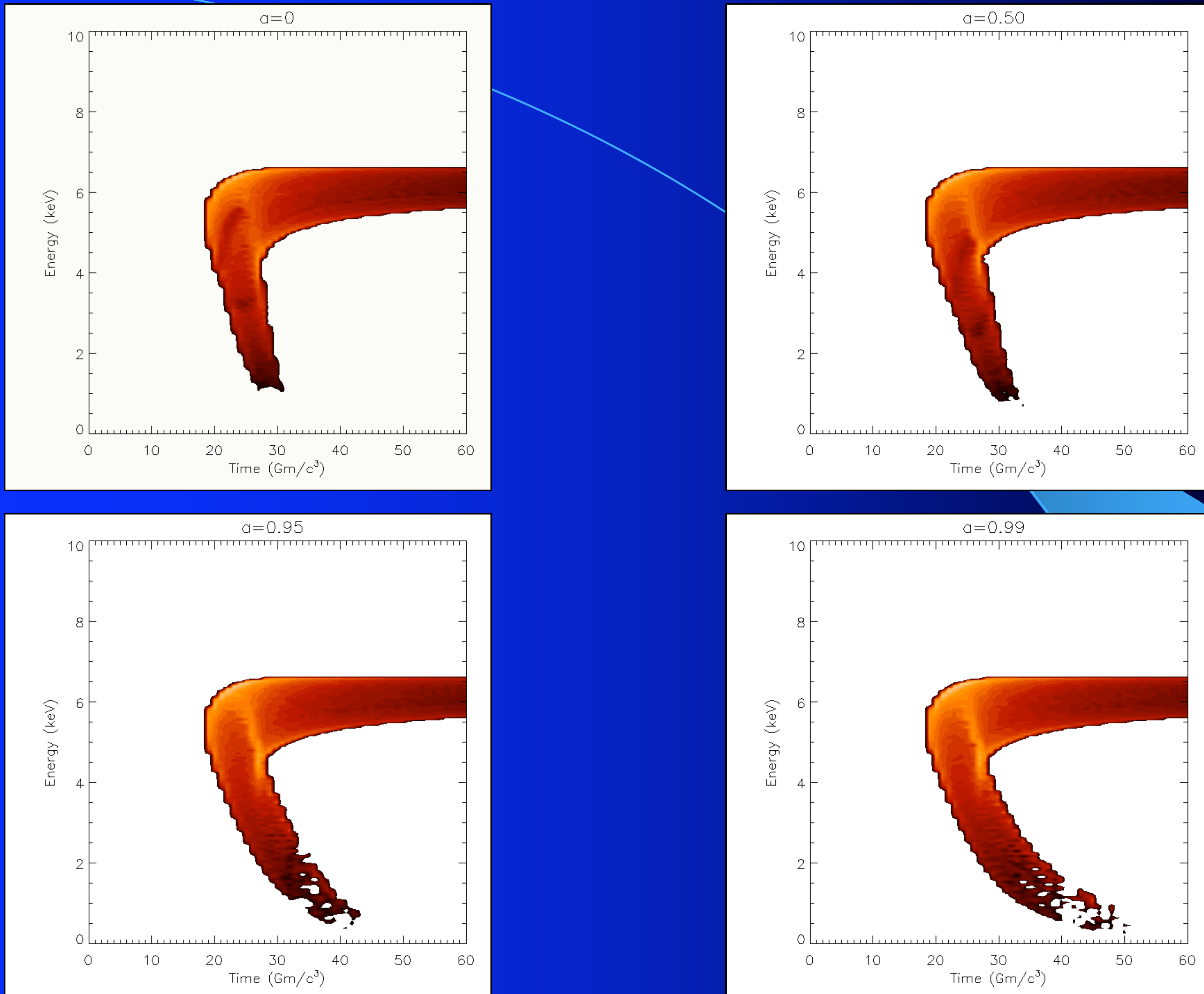


Chandra-HETG data on NGC3516
(Turner et al. 2002)



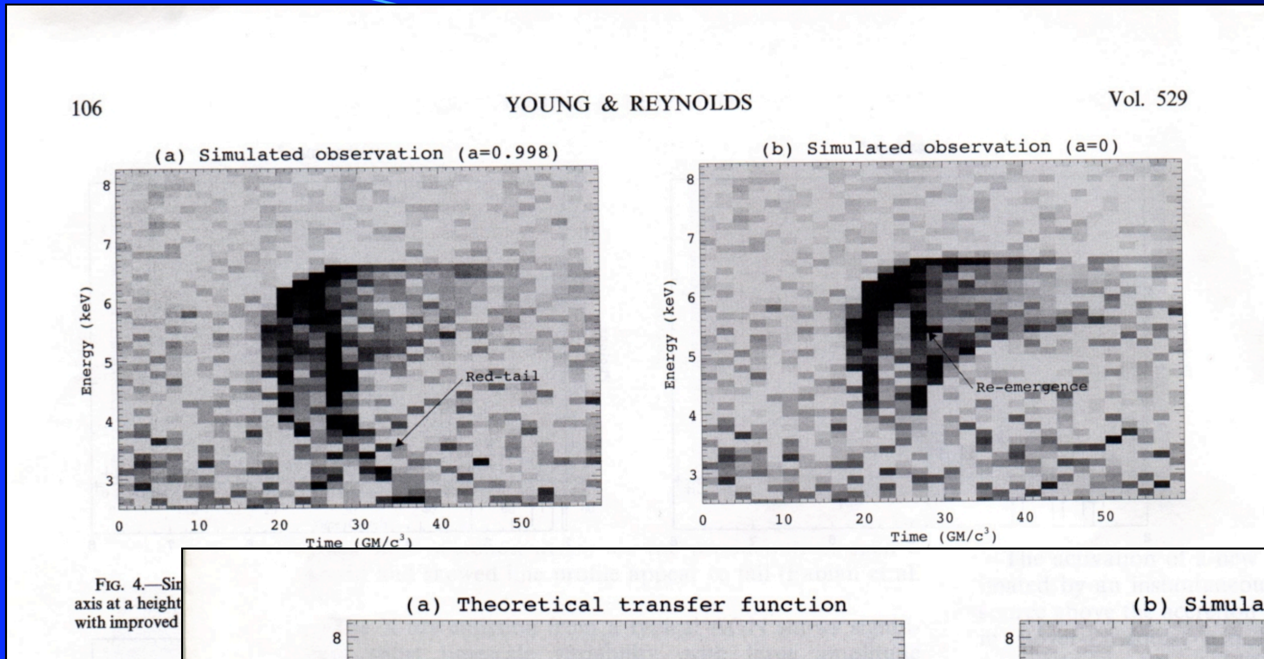
Simulation results for inclination
of 20 degs (summed over 2 full orbits)

A prime science target for Astro-E2



Reynolds et al. (1999)

Young & Reynolds (2000)



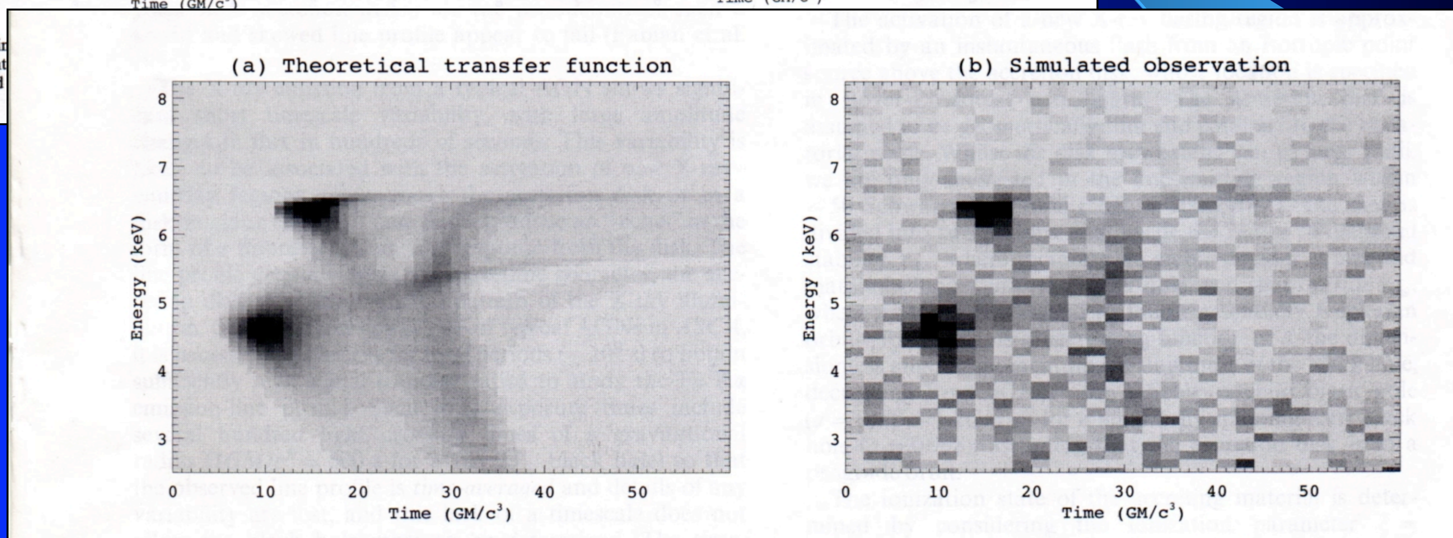


FIG. 7.—Panel *a* shows the theoretical line response to the two overlapping flares described in the text. Panel *b* shows the simulated line response as seen by *Constellation-X*. The individual transfer functions of the two flares can be discerned. The data have been rebinned to produce these figures with improved signal-to-noise ratio.

Constellation-X simulations